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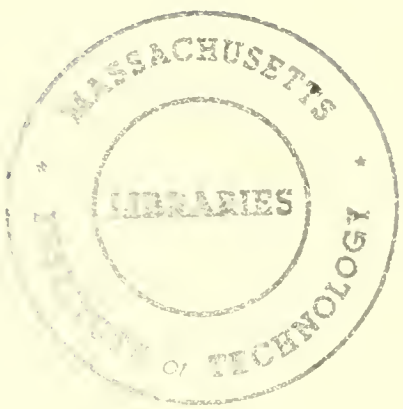
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Management of National Technology Programs in A Newly Industrializing Country--Taiwan

Jong-Tsong Chiang

March 1990 WP 3138-90-BPS

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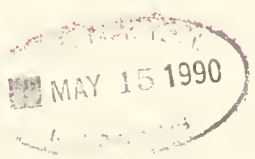

Management of National Technology Programs in A Newly Industrializing Country--Taiwan

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Abstract

As a technological follower country, Taiwan until the mid-1970s was characterized by a "supply-side" policy, loose connection between R&D community and industry, and low R&D expenditure in absolute terms and as a percentage of GNP. The "American challenge" which suggested "big is beautiful" also in the R&D investment in the 1950s and 1960s meant little to Taiwan because Taiwan was then "too underdeveloped to be challenged" and its indigenous R&D capability was too weak to launch any projects of considerable size, let alone "big science" or "big technology." However, the recent "Japanese challenge" manifested a way to catch up with western forerunners through national innovation system well illustrated by its VLSI national program in the late 1970s. This new "model" triggered an aspiration in Taiwan, and national technology programs aiming at industrial competitiveness became a government new strategy around 1980 to restructure science and technology development systems and to guide large R&D investment. In fact, this strategy re-oriented Taiwan's policy from the "supply-side" rationale to a "whole innovation process" approach emphasizing the "demand side" perspective. Taiwan's experience suggests the following lessons, most of which may be of timely relevance to other developing or newly industrializing countries.

1. A "national champion" who could acquire huge resources and integrate all essential functions is of pivotal importance in this endeavor.

2. An institutional adjustment to facilitate nationwide coordination and an overall development framework to upgrade infrastructure and general capabilities are indispensable for this "structural transition."

3. Organizing foreign prominent advisors at the national level to help important decision making is very desirable because there was relatively little domestic experience in managing large scale programs.

4. Public applied R&D institutes have to take major responsibility given the weak technical capability of domestic

industry, but they may easily become isolated "enclaves" due to weak upstream research community, downstream industry and complementary technologies.

5. A national program in an "imitative" country could benefit greatly from technological convergence and standardization in advanced countries because of the clear direction for concentrated efforts.

6. Transfer of highly complex and dynamic technology from R&D institutes to industry involves high "switching cost" on both sides, and requires special effort in overcoming the uncertainty imposed by formal organizational boundaries in between.

7. The issue of complementarity between large scale process technology, which is beyond private sector's capability, and entrepreneurial product design, which had better be handled by private sector, points to the possibility of a novel form of "strategic alliances": the state responsible for process technology and the private sector taking care of product designs.

8. Technical service to industry could be enhanced by special task forces led by experienced industrial technologists independent of R&D institutes which usually lack extensive industrial "field experience" as well as interest in the seemingly "low-end" technical service.

9. R&D, technical service and managerial service functions could be made mutually supportive by placing them under common leadership, within the same organizational boundaries or at the same locations.

10. The mobilized national efforts to implement national programs could reciprocally strengthen the advisory and project evaluation functions of administrative systems, strategic positioning of major R&D organizations, and enforcement of grand development plan in infrastructure and general capabilities.

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1. Introduction

Unlike its economic development which is often regarded as one of the models in the group of developing countries, Taiwan's experience in innovation and science and technology (S&T) development has hardly attracted foreign attention due to its apparently follower position and insignificant presence in the international arena. Moreover, there have been very few, if any, relevant studies or records kept by international organizations, such as World Bank and United Nations Organizations, because Taiwan has been officially isolated from most of these activities for nearly two decades due to Communist China's "one China policy" and endless intervention in Taiwan's international affairs, which it thinks may lead to taking Taiwan as an "independent" entity, including even academic cooperation and macro record keeping. Therefore, relevant literature available in foreign language is scanty.

In fact, even in Taiwan there was no national statistics about R&D activities until the early 1980s. In the academic world, so far only a small community in industrial economics has paid considerable attention to this field.[1]

As a result, the study of Taiwan's national technology programs from a managerial point of view has to be rather "self-dependent." In this research, three sources of information are heavily relied upon. The first is a large scale empirical study mainly done by the author under the auspices of the Industrial Technology Research Institute (ITRI, Taiwan's largest industrial R&D complex) in 1979 and 1980 about industrial R&D and technology transfer. This study includes 14 in-depth case studies and quite detailed questionnaire survey (with overall respondent rate 48%) to 73 university engineering departments, 49 engineering and technical consulting organizations, 12 industrial associations, 131 industrial product importers, 170 companies with foreign investment, 180 companies with foreign technical cooperation, and 689 manufacturers covering 19 "sub-industries" in chemical, mechanical engineering and electronic industries. The main findings of this study were crystalized into a report titled *Industrial Technology Development*

and Transfer in Taiwan (in Chinese) published by ITRI at the end of 1980. This study is unique in Taiwan in that it investigated concrete industrial technological issues without much abstraction. It also represents a historical record until the new era beginning around 1980 when the national technology programs and the first grand national S&T plan, the two unprecedented national thrusts, were initiated.

The second major source of information is the results of a seminar series "the Formation of Big Science and Technology Programs" designed and organized by the author and formally sponsored by the Science and Technology Advisory Group for Premier (STAG, the actual initiation center of Taiwan's national programs) during March through June in 1985, about 5 years after the launching of first 4 national programs and 3 years after the other 4 programs.[2] The task force for this seminar series was made up of about ten groups of experts invited from a variety of institutes. They all had strong technical background (many with doctoral degrees) and at least some managerial experience (e.g., department or project leaders), but did not have personal stake in the programs they studied. They reviewed the formation and management of Taiwan's large scale programs and presented the results in the conference room of STAG with participation of STAG core staff and a limited number of concerned people from relevant organizations.[3] The whole series consisted of 31 presentations, of which about half were given by program or department leaders up to deputy minister level about their own experience and viewpoints.[4] Although many findings and judgments were disputable given the complexity of the programs and the rough research methods then, this series provided the first "systematic" information about the management of large scale programs, which could support further analysis from a cross-technology perspective.

The third information source is the author's working experience in ITRI, STAG and some related organizations during 1978-1985 with one-year break in Japan. As a practitioner, he participated in some policy formulation and implementation. As an observer, he watched much important decision-making and many

practices. Until mid-1985 he was an "insider" in Taiwan's national programs.

The paragraphs that follow draw materials from the above three sources. Relevant information was updated through frequent correspondence with some organizations and decision makers in Taiwan after the author left there in mid-1985. To reduce undue subjectivity which would not be easy to entirely avoid in a qualitative analysis of complex phenomena like this one, much background and supportive information is provided in notes. But still some description of macro pictures, which is essential for understanding national programs, reflects the author's judgment without rigorous study support. It is hoped that these limitations would not "contaminate" seriously the main conclusions.

2. The Emergence of National Programs

2.1. Background

Until the late 1970s, Taiwan's industry rarely relied on domestic R&D and technical organizations for their key technology. Most got technology from customers and suppliers of equipments, materials and parts,[5] and foreign sources occupied a significant position.[6] In fact in local R&D community the reverse of "NIH" ("not invented here")[7] prevailed, and few R&D results could be expected to significantly contribute to domestic industry. In other words, the connection between industry and professional S&T community was very loose. On the government side, however, there had not been strong initiatives to remedy this weakness.

In the government, the National Science Development Steering Committee under the President-presided National Security Council and the National Science Council under the Premier, both established in 1967, were the two leading bodies. The former, though high in position, normally had its advisory function diluted by other more urgent issues. The latter, which was supposed to coordinate R&D activities across ministries, could only use its very limited funds to support fundamental research in universities and several research centers, and did not possess substantial influence on many much

larger projects sponsored and administered by other agencies. Additionally, leaders in these two organizations normally came from the academic community, and had little direct experience in industry. So the typical approach to S&T was to increase investment in R&D; the main argument was for long-term development; and the "last shield" was the cultivation of human resources in case there was doubt about the output. In other words, the policy was input-oriented, and there was little comprehension of the whole innovation process.

This scenario lasted until the 1970s, when several issues compelled the S&T development in Taiwan to change its locus.

First, the skyrocketing prices of energy and many raw materials forced Taiwan's economy to undertake structural change. This was due to the fact that four fifths of Taiwan's energy consumption was based on oil which was nearly all imported.[8] Besides, Taiwan was almost devoid of any important natural resources for industry[9] and raw materials accounted for the lion's share of import.[10] Therefore, to increase the value-added in this very international trade-dependent island[11] was an emergency.

Second, the contribution share of technology progress to economic development declined constantly from about four fifths in the 1950s to half of that in the mid-1970s.[12] This trend revealed the long, relative negligence of industrial technology base despite the overall satisfactory economic performance.

Third, many new technologies emerging in advanced countries seemed to point out a promising way. To take part in this new era became a new national aspiration. Meanwhile, Japan's VLSI national program also gave some impetus to a more active role of government, especially in strengthening the indigenous industrial technology base.

2.2. National Leadership

In this "new technology movement," K.T. Li was asked by the then Premier to take charge of S&T development in the government. Li, often referred to as "the father of Taiwan's economic development," had a very high reputation throughout the country

and great influence in the government system. Over the past two and a half decades until the mid-1970s, he served as the president of Taiwan's then largest ship-building company, vice chairman of the Council for Economic Planning and Development, Economic Minister and Finance Minister. His advanced science education and research background, professorship in both modern physics and economics, and broad knowledge about modern S&T also made him an acquaintance of most leaders in the local S&T community. These qualifications made him an authoritative spokesman from industry and government sectors who could challenge the S&T community and, at the same time, a friend of the S&T community who could acquire more resources, at least from the government. He thus became a powerful interfacing and integrating leader in national S&T development. Under his direction, many important policies and measures concerning the overall S&T framework were adopted, and the national strategic technology programs were launched around 1980.

2.3. Initiation of Programs and Institutional Arrangements

Until the mid-1980s, Taiwan's national strategic programs centered on eight fields: energy, automation, information, materials, biotechnology, electro-optics, hepatitis B control and food. The first four were officially announced in 1980 and the rest in 1982. After that, four more topics--environmental S&T, disaster prevention, synchrotron radiation and ocean technology--were added in 1988. But they are too "new" for this research and thus beyond the scope of the following discussion.

As regards the first eight programs, except for the last two, the purposes could be generally inferred by studying the courses taken by many advanced countries. Nevertheless, the initiation of biotechnology program deserves some elaboration.

After the emergence of genetic engineering in the mid-1970s in the U.S., "new biotechnology" was also a hot topic in Taiwan. But the indigenous base was very thin. In January 1982 a large conference on genetic engineering was held in Taipei (the capital city of Taiwan). This conference was well organized with attendance by

some five hundred people from local R&D community and dozens of overseas Chinese experts. After the conference, the latter group led seven days' panel discussion and demonstrated lab works for local community with many experimental materials and reagents brought back by themselves. This event decisively prompted the announcement of national biotechnology program right after the conference. It also showed the potential impact of "invisible college" of overseas Chinese professionals upon domestic S&T development.

The initiation of the hepatitis B control program was decided upon because hepatitis B was a common chronic disease in Chinese society,[13] while the understanding of the viral, pathological and transmission mechanisms, and the prevention and treatment were still at a primitive stage.[14]

The reason that food technology was included was said to be based, more or less, on political consideration which meant to reserve some resources for the agricultural and food R&D community which had remarkable historical records.[15]

Since these programs were intended to be long-term and not one-shot efforts, new institutional arrangements were required. After summoning the national S&T meeting for the first time in 1978 to declare the new government emphasis on S&T, two small offices--Applied Technology R&D Group (ATG) and Science and Technology Advisory Group (STAG)--were set up directly under the Premier to coordinate nationwide programs. However, ATG and STAG were sometimes regarded as equivalent to each other because both were under Li's leadership and there were few staff in ATG. In each ministry, a Science and Technology Advisory Office was also established for ministry-wide S&T affairs.

Besides, several prominent foreigners in the international S&T community and high-tech industry were invited to be the S&T advisors to the Premier, and were honored as minister-equivalent guests. Among these advisors were a vice president of IBM, the late chairman of Texas Instruments, a former French Minister of Industrial R&D, the president of the Illinois Institute of Technology, a former chairman of the U.S. National Academy of Sciences, the vice chairman of U.S. Electric Power Research Institute and the vice

chairman of TRW. These advisors gave suggestions regarding broad policy as well as specific R&D issues, promoted international cooperation, and helped converge the normally diverse opinions in S&T development. They, therefore, directly and indirectly strengthened the national strategic programs. With the active participation of these foreign advisors and local leaders, the Science and Technology Advisory General Meetings were held twice a year and presided by the premier. These meetings became very important regular fora, in which many ideas were proposed, openly discussed, internationally compared, and then executed by the participants through their own organizations.

3. Strategy and Management of National Programs

3.1. Key Components of National Programs

In each national program, the initial effort was to develop and integrate the key functions and relevant systems. The responsibility assignment of the production automation program is a typical example. Under the Joint Program Executive Group, there are five divisions composed of related agencies (those with * being leading ones in individual divisions):

- Industrial Automation Division
  - Industrial Bureau*
  - Factory Automation Task Force
  - Small and Medium Enterprise Department
  - Metal Industry Development Center
  - China Productivity Center
  - China Textile Research Center
- Automation Industry Division
  - Mechanical Industrial Research Labs* (under ITRI)
  - Industrial Bureau
- Automation Technician Training Division
  - Vocational Training Bureau*
  - Small and Medium Enterprise Department
  - Metal Industry Development Center
  - China Productivity Center

China Textile Research Center

- Automation Engineer Education Division
  - National Science Council*
  - Ministry of Education
- Financial Support Division
  - Council for Economic Planning and Development*
  - Ministry of Finance
  - Budgeting Bureau of Premier Office
  - Development Bank

The above list indicates three major elements in all industrial technology programs: technology development, education and training, and finance. Nevertheless, the latter two are primarily taken care of by other regular government functions. Therefore, these national programs in effect only have considerable discretion in technological activities. And in this dimension usually there are two major parts: a limited number of large-scale R&D projects and "custom-made" technical service to related industries.

For programs including non-industrial purposes, some different functions have to be added. In this regard, the hepatitis B control program is an example. In this program the Health Administration and the National Science Council are two major responsible agencies. The latter takes care of scientific enquiry into hepatitis B and R&D on vaccine and diagnostic reagents. The former is in charge of prevention plan, vaccination plan and medical care through public and private hospitals and health care network.

3.2. Whole Innovation Process Approach

In all national programs, government, industry and academic community are expected to collaborate closely. In fact, the concept of "whole innovation process" was adopted in these programs, and could be illustrated by the biotechnology program shown in exhibit 1.[16]

By identifying the weak parts in the whole innovation process, a number of important institutes relating to national programs were established as follows (information until mid-1988 and notations BR

and ARD representing basic research and applied research/development respectively):

- Institute for Information Industry (ARD, for software development and promotion) (1980)
- Institute of Biomedical Science (BR, under National Academy of Sciences) (1981)
- Energy Research Labs (ARD, under ITRI and later merged with Mining Research and Service Organization) (1981)
- Institute of Atomic and Molecular Science (BR, under National Academy of Sciences) (1982)
- Institute of Molecular Biology (BR, under National Academy of Sciences) (1982)
- Materials Research Labs (ARD, under ITRI) (1982)
- Institute of Applied Mechanics (BR, under National Taiwan University) (1983)
- Micro-Electronics and Information S&T Research Center (BR, under National Chiao-Tung University) (1983)
- Development Center for Biotechnology (ARD) (1984)
- Materials Science Center (BR, under National Tsing-Hua University) (1985)
- Synchrotron Radiation Research Center (BR) (1985)
- Center for Measurement Standards (ARD, under ITRI) (1985)
- Electro-optics and Peripherals Development Center (ARD, under ITRI) (1987)

These institutes constituted a large part of national long-term investment in the infrastructure for S&T development.

3.3. Major Role of Applied R&D Institutes and Collaboration

Because most national programs were to strengthen industrial competitiveness, the industry was supposed to play a critical role in these programs. However, the industry's overall innovative capability was weak. Just by simple conjecture, no firms in Taiwan were qualified for an "offensive" innovative strategy which is based on very strong development capability as well as applied research and product design engineering and aims at being first mover that has to take the responsibility of educating potential customers. A

"defensive" strategy was also beyond the capability of Taiwan's industry, because this strategy, while avoiding first mover's risk, seeks to catch up quickly with minor innovations, improvements or product differentiation, and thus also demands very strong development and product engineering capability. In fact, leading firms in Taiwan could at best adopt an "imitative" strategy. These firms followed the leaders in established technologies. They relied mainly on cost advantage through production efficiency and did not aspire to leap-frog or keep up with the innovative leaders like those with "defensive" strategy. As to the rest of the industry, most firms basically accepted satellite and subordinate position in relation to other stronger domestic and foreign firms, and usually depended upon the latter to supply technical specifications and advices. Their strategy could best be described as "dependent."[17] Although this profile of Taiwan's industry seems to be oversimplified without rigorous study support, the manpower structure in information industry in the mid-1980s as shown in Exhibit 2[18] could roughly support the above assessment. It was found that, while system development (according to system specifications and product engineering designs) designers and manufacturing engineers were in abundant supply, experienced managers and design engineers for product concept definition, system design and product engineering design were very few in Taiwan. Given that information industry played a strategically leading role in Taiwan,[19] its technical capability for at best an "imitative" strategy might well suggest the general upper limit of industry's technical potential in Taiwan.

R&D investment is another rough indicator. The national expenditure as percentage of GNP was only 0.66 in 1978, 0.84 in 1979, 0.72 in 1980, and around 1 even in the mid-1980s. And the R&D expenditure as percentage of sales by industry had not surpassed 0.5, albeit varied across industries, until the mid-1980s.[20] These figures clearly point to Taiwan's very limited engagement in R&D activities relative to most industrialized countries.

As a result, applied R&D institutes had to take the principal responsibility in most industrial technology programs. Their central role and collaboration with other parties could be illustrated by

Exhibit 3, whose main points are as follows. On the one hand, government and other sponsors give advice and guidelines as well as financial support to applied R&D organizations, and evaluate their performance. Universities and basic research labs do upstream and fundamental research and transfer the results to applied R&D units. On the other hand, industrial product manufacturers (e.g., machinery makers) and users (e.g., other industries using equipments or systems) are the clients to applied R&D organizations. To facilitate cooperation, some kinds of task forces with participation from multiple parties are encouraged. Based on this collaborative framework, the performance of major applied R&D institutes and their cooperation with industry are crucial to the success of national industrial technology programs.

3.4. Limits to Innovation Strategy

After the initiation of national programs, the Chemical Industrial Research Labs (CIRL, the new name for the Union Chemical Labs) first faced big difficulties. CIRL is one of the most senior industrial R&D institutes in Taiwan. It was originally established by the China Petroleum Co. and mainly worked on petrochemical related R&D. When the materials technology was proposed to be one of the eight national foci, CIRL naturally became the best candidate to take the lead. But it was criticized for not being able to respond to local needs and to capitalize on new technological opportunities.[21] So the new Materials Research Labs (MRL) was established in 1982. However, MRL was evaluated as unsatisfactory in terms of strategy and selection of R&D topics several years later.[22]

In fact, these two labs have successfully developed a number of new materials, such as second generation semiconductor materials (i.e., III-V compounds), high polymers, fine ceramics, sensing materials, etc. Besides, MRL is even among the few pioneers in high temperature superconductor research in the world.[23] Nevertheless, local industries could hardly make use of their R&D results, and they lacked scale-up capabilities. Furthermore, many downstream and complementary technologies (e.g., processing, equipments, instrumentation, testing and quality assurance) and application

contexts (i.e., relevant industries) were either non-existent or too weak. Therefore these research achievements are like isolated "enclaves." There is little chance at least in the "near" future of substantive commercial applications.

By contrast, the above problems seem not to be so serious in the biotechnology program. In this program a special institute, the Development Center for Biotechnology (DCB), was set up in 1984 to be responsible for commercial development. The reasons are at least twofold. One is that the possible scale-up centering around several clusters of technologies, such as genetic engineering, cell fusion and tissue culture, is so far still relatively moderate. The other reason is that "new biotechnology" basically is a new process approach to topics, of which most have already been rather well defined or even inflexible in biochemical compositions (even if many targeted products have not been very successfully produced by traditional methods). In the materials program, product functions rather than product compositions are the foci, so there are many potential product substitutes and, accordingly, process approaches. Far greater risk is thus involved.

However, the biotechnology program is not without its own difficulties. One is the weak upstream research community.[24] Hence it has to take some time to generate enough research results for DCB to do further development. So DCB has to seek cooperation from abroad for the time being. In view of DCB's far less experience in bioprocess (which is normally viewed to be proprietary and an important origin for competitiveness in the advanced countries[25]), this strategy is questionable.

Another insurmountable hindrance is the very weak pharmaceutical industry. One indicator is that even GMP (Good Manufacturing Practices) system was not implemented in Taiwan until 1982. This means that many medicines now under R&D in the biotechnology program would face more or less similar difficulties in commercialization as in the materials program.

3.5. Selection of R&D Topics

Though without the title of national programs, some early R&D projects were very large in scale and paved the way for later national programs. Projects for integrated circuits (ICs) and computers are good examples.

In retrospect, a very risky decision in the early days was the selection of IC technology for the Electronics R&D Center, which later was renamed the Electronics Research and Service Organization (ERSO) and played the leading role in the information technology national program. In 1974, CMOS technology was selected under the recommendation of several overseas Chinese experts in the U.S. At that time, CMOS technology just accounted for a very small fraction of the market share (less than 10%), lagging far behind PMOS (about 35%) and bipolar (about 50%).[26] Even in 1982 CMOS did not differ much from its previous situation (10%), still behind bipolar (50%) and the fast emerging NMOS (37%). But PMOS had declined swiftly to an even less significant position (6%) than CMOS. However, since then the CMOS market share went up quickly to about one fifth in the mid-1980s and is expected to attain half of the IC technology market by 1990.[27] The decision to bet on CMOS proved appropriate for Taiwan because CMOS, albeit with lower computing power than NMOS and bipolar, is lower in prices and suitable for calculators, personal computers, work stations and even mini- and superminicomputers, and the production of these products in a rough sequence is the locus of Taiwan's information industry in the late 1970s and 1980s. Therefore, CMOS technology has greatly contributed to downstream electronics industry. By contrast, South Korea in the mid-1970s targeted PMOS. It had to change to CMOS later.[28]

In computer technology, before the boom of personal computers in the late 1970s, ERSO focused mainly on minicomputers. But by the end of the 1980s there was concern about the possibly widening gap with U.S. leading minicomputer companies. Fortunately the introduction of microprocessors and personal computers, exemplified by Intel 8086 (1978) and Apple II (1977), changed the whole scenario. Taiwan's firms entered the market by copying Apple II in late 1981, 56 months after the original products.

Detecting the great opportunity, ERSO joined the local industry and modeled IBM PC based on Intel 8088. ERSO completed prototypes in April 1983, and local industry introduced clone computers in September that year, which was 25 months later than IBM. These products were confirmed formally by IBM in May 1984 to be not infringing IBM's proprietary rights. This was a great success of joint forces of ERSO and local industry. Then Intel 80286-based IBM PC/AT was introduced in August 1984. ERSO and local industry followed. Only 11 months later Taiwan's clone computers appeared in the market. In the next generation PC competition, IBM PC/RT model entered the market in August, Compaq PCs in September, but ERSO's prototypes in June, and Taiwan's commercial clones in November, all in 1986 and all based on Intel 80386 which was introduced in November the previous year. This remarkable progress made the local industry so confident that it, through computer association, declared the determination in a press, right after IBM's announcement on March 2, 1987 of a new series of PCs using its self-designed application specific ICs (ASICs) up to 80%, that it could supply new IBM compatible PCs within six months after the first introduction of IBM products.[29]

In 1988 Taiwan's total export value of personal computers was USD 1.15 billion, the world's third largest suppliers (after the U.S. and Japan) and with 40% sold under self-brands.[30] As regards ERSO's contribution, about 30% of the export value of IBM PC/XT and PC/AT clones respectively was made by local firms with "core technology" transferred from ERSO. In 1985, the figure was only 8%.[31] In 1989, ERSO announced its goal to complete superminicomputer prototypes in 1990 and 3-D graph workstation prototypes in 1991.[32]

The above history points to the fact that the convergence of personal computer models (i.e., IBM PC) and memory IC technology (i.e., CMOS for microcomputer level products) and the availability of key components in the open markets (especially microprocessors) have collectively provided enormous opportunity for Taiwan's ERSO and industry to narrow the lag behind the world leaders. But when the focus moves up from lower-end and more "paradigmatic" fields to higher-end and more dynamic fields, the challenge still looks

insurmountable. Taiwan tries to incorporate new technology, such as UNIX system, RISC (reduced instruction set computer architecture) and multiprocessors, into its products as soon as possible. But it is basically a standard-acceptor. When RISC standards were competed among SUN (APARC), MIPS (R3000), Motorola (MC88000) and Intel (80960) without apparent dominant designs, it is said that few organizations invested in related R&D.[33] Certainly this strategy may be reasonable for a follower like Taiwan and Taiwan may have improved its relative position in the international community for the past one decade. But it in some way confines the scope of a national program. Recently ERSO announced its policy to reduce the weight of specific product development and demonstrative production, and to increase the weight of "more generic" R&D to support broader applications.[34] This may be seen as a sign for a more "offensive" strategy in this "imitative" and "dependent" country.

In contrast with the information technology program which, though including a variety of items, has ICs and computers as major foci, the automation program has few "automation products" which do not require much adaptation to specific application contexts. So it is difficult to find a small number of foci to "universally" meet clients' needs or be suited for mass production like memory ICs and personal computers. The interfacing issues between R&D labs and industry are very diverse. Overemphasizing some product items without paying ultimate attention to the rather inseparable application contexts has potential hazard. And this is what the Mechanical Industry Research Labs (MIRL), the leading R&D organization in the automation program, experienced. MIRL succeeded in developing a series of new "automation products," such as FMS (flexible manufacturing system) pilot plant, automatic storage and retrieval systems, and robots for loading/unloading, welding and spray painting. But few local firms could make use of the technology without much adaptive effort. Therefore MIRL's contribution through technology diffusion was challenged by industry and professionals around 1984, though its demonstration of "modern automation" was applauded by mass media.[35] To rectify this

weakness, MIRL started to strongly promote technology transfer to and joint development projects with industry in 1984 and 1985.[36]

In nuclear energy technology, a different picture emerged. The original rather ambitious attempt was largely modified. The reasons are manifold. First, the high technology complexity and the deep concern over cost, safety and environment made the pursuit in the direction of technological self-dependence very prudent. Second, the expected domestic market of at most 4 stations with 8 reactors until the end of this century seemed too small to justify large scale investment in establishing local capabilities. Third, two joint ventures of two large local engineering companies respectively with U.S. architect-engineers, Ebasco and Bechtel, had not progressed satisfactorily in upgrading indigenous design capability. Therefore, the technology priority was put on construction, operation, maintenance, safety, project management and plant design standardization and optimization, rather than local content of high-tech parts, components and designs.[37] In view of the average availability of 4 BWRs' 82% (6 years' commercial operation) and 2 PWRs' 77% (2 years' commercial operation) in 1987, and the average unit generating cost of USD 0.025/KWH of nuclear power plant (as opposed to USD 0.042/KWH of coal plant and USD 0.067/KWH of oil plant),[38] the technological decision seems "pragmatic" and appropriate for Taiwan, because even the targeted foci as mentioned above demand strong technical capability and strict discipline support, and by advanced countries' standards (e.g., availability rate) Taiwan's operation performance seems acceptable.[39]

Of these national programs, the R&D of vaccine and diagnostic reagents in the hepatitis B control program and the alternative energy development in the energy program had little difficulty in selecting R&D topics. In the former case, the initial market (Taiwan), the product content, and the targeted processes were all well-defined at the outset. In the latter case, R&D on non-fossil energy, except nuclear energy, gradually lost its appeal owing to the recent oil price decline and the low feasibility of large-scale or widespread commercial applications in the near future.

3.6. Technology Transfer from R&D Institutes to Industry

Because applied R&D institutes are responsible for developing many key technologies, inter-organizational technology transfer from them to industry is essential to the ultimate success of most industrial programs. Here only the IC project, the largest single project in all national programs, would be analyzed owing to its importance, difficulty and dramatic history, which may provide novel lessons concerning technology transfer.

As noted previously, ERSO, or more precisely, its Integrated Circuit Development Center (ICDC), was responsible for Taiwan's pioneering IC R&D. At the end of 1979, ERSO began its plan to transfer the technology of 4K-b DRAM using 3" CMOS wafers to a newly established private firm, Lien Hwa Co. (LH). This plan was handled by the director of ICDC, who was also the deputy director of ERSO. Many difficulties arose. Then another deputy director of ERSO responsible for administration and marketing moved to LH and became its president. In the meantime, some key personnel from ERSO also took over LH's main functions and worked with ERSO for technology transfer. The mission of transferring up to 3 micron Si-gate CMOS and NMOS process technology and product design of some 60 items was finally accomplished. The whole plan took three years and four months.[40]

Back in 1975, ERSO began to introduce in RCA's "package" CMOS technology. ERSO's 51 persons received 363 person-months' training from RCA which assigned 81 persons for this purpose. Half a decade later, ERSO allocated 250 person-months to help construct LH's factory, and LH's 31 persons received 262 person-months' training from ERSO which assigned 65 engineers, about one third of its total professional staff, to help this mission. But this time, in addition to ERSO's one deputy director, ICDC "lost" three department managers of testing, marketing and quality assurance, two division heads of IC fabrication department and several other engineers to LH. In fact, presently nearly all LH's executives are from ERSO.[41]

Then ERSO moved into 16K-b DRAM on 4" CMOS wafers. But the new negotiation of technology transfer between ERSO and LH was

not smooth. LH thus decided to develop 16K-b DRAM by itself and it succeeded.

Later, ERSO shifted to 64K-b DRAM in 1984 and 256K-b DRAM in 1985, but met bottleneck of low yield rate. LH also faced big difficulties. Meanwhile, a private company, Kuo Shan Co. (KS), possessing a manufacturing division in Taiwan and a product design division in U.S. Silicon Valley, successfully commercialized 64K-b DRAM, and continued to proceed into 256K-b in 1985 by renting part of LH's factory and facilities. LH's successful experience of cooperation with KS and another product design company encouraged LH to plan an ambitious expansion of about USD 175 million investment to get into 256K-b and 1M-b DRAM and 256K-b SRAM using 6" wafers when it knew that KS was short of financial resource.

As a matter of fact, LH's new plan also aimed at competing limited local resources with two other ongoing plans. One plan was to establish a new corporation, Taiwan Semiconductor Manufacturing Co. (TSMC), based on ERSO's process technology and with investment of about USD 300 million from government, local firms and Philips Co. of the Netherlands. Its original proposal to set up a DRAM production plant was later adjusted to one mainly for ASICs due to the concern with Japanese very strong position in standard memory ICs. The other plan was the National Science Council's novel idea to invest USD 200 million to establish a modern factory with common facilities to lease to private companies with their own product designs.

These three parallel forces evoked great anxiety as to whether the combined manufacturing capacity could be fully "digested." So high level coordination and negotiation were underway. Finally, the National Science Council gave up its plan. TSMC was set up in April 1987. And the new president of ITRI (inaugurating in the late 1985), under which ERSO is one of the five major R&D organizations, concurrently became the chairman of both TSMC and LH in 1987. LH's new investment plan was then postponed indefinitely.[42]

Under this arrangement, KS had little chance to revive and thus faded away. LH risked losing continuous challenge to its well-

integrated capabilities in IC product design, commercial production and marketing. And ERSO had to again start another round of large scale transfer of 1.25 micron CMOS and NMOS technology to TSMC. This second plan started in 1987. Until mid-1988, ERSO "lost" 98 professionals and 46 operators, all experienced, to TSMC.[43] In the meantime, TSMC also had to accumulate its own learning experience.

Taiwan's "IC history" reveals several critical issues inherent in the transfer of highly complex and dynamic technology. Because of the technology receiver's heavy reliance on the R&D institute for fast moving technology and the R&D institute's strong commitment, including personnel transfer, needed to implement the difficult task, the switching cost (i.e., the cost incurred by changing partners) for both sides is very high. Due to the formal organizational boundaries existing between R&D institute and firm, there is possibility that the cooperation for one generation technology may not continue in the next generation. Then the R&D institute would face big initiation cost again, and the firm may become technologically obsolescent soon. Therefore the present solution in Taiwan seems to be of temporary use only and has not solved the "structural problems."

Another issue concerns the balance between product design and process capability. In this respect, two levels, business and national, are involved. At the business level, the rationale underlying so-called "strategic alliances" between small companies good at product innovation and large companies strong in production base could apply here. At the national level, since the economic scale of IC manufacturing has become so large that even the entire domestic ASIC design capability can not fully utilize it, international alliances become advisable. In this case, there was great doubt about the magnitude and continuation of Philips' order which was supposed to be the major source of product design at the beginning stage. It turned out, however, that the announcement of establishing TSMC, a specialist manufacturer, triggered the rise of IC design industry. The total number of local ASIC design companies reached 40 in July 1987,[44] which was fifteen more than just two months before and ten times the previous year.[45] In fact many of these design houses were ERSO's "spin-offs."[46] As before, ERSO continued to cooperate with IC

design houses, including the largest local design firm, Tai-Hsin, and several design centers invested by Philips, Motorola, etc., in technology transfer and training. Though the long-term effect still remains to be seen, the fast growth of IC design industry has largely mitigated the worry as noted above. All this could be attributed to Taiwan's unique pattern of IC development with ERSO as the center of technology transfer and diffusion.

3.7. Challenges to Technical Service

Technical service to related industries is particularly important in the automation, information, materials, and energy programs. Nevertheless, few responsible organizations had satisfactory records.

In the materials program, the original plan of the Materials Research Labs to assist local industries in materials selection and inspection, and process improvement has not been pushed hard.[47] Similar situation exists in the Energy Research Labs. Its long negligence in the high-return energy conservation has often been criticized.[48] These two labs have vast industries in need of their service, but they are not active nor successful in this line.

For these R&D institutes, technical service is not considered to be really challenging or "high-end." In the meantime, most people in these institutes lack the necessary industrial experience to diagnose and solve the field problems in a "professional" manner. Factory automation may well illustrate the challenges. Factory automation concerns operational parameters, materials used, equipments, instrumentation, tooling, production sequence, layout, product design, quality control, human factors, etc. So key people responsible for automation service need quite extensive field experience to acquire the multi-faceted expertise.

For energy conservation, two more teams, in response to government request, were organized by the two public monopolistic energy suppliers--China Petroleum Co. and Taiwan Power Co.--to help industries save oil and electricity respectively. But it is said that the people selected for this mission were not necessarily the competent but instead those available.[49] Meanwhile, these two energy companies did not pay real attention to this task. So the

technical service was not active. The reason seems rather self-evident. These two companies' major role is to supply energy, not to save energy. So there is role confusion and even conflict in the energy conservation service groups underwritten by them.

To solve this dilemma, a new independent Energy Conservation Task Force (ECTF) was formed in April 1983 directly reporting to a new Economic Minister. According to ECTF's plan, heavy energy consumption industries would be served first. But most work appeared not easy. Energy users in this category usually need to improve their energy utilization in a whole system approach which also calls for large capital investment. Minor operational and equipment adjustments have only marginal effect. So the threshold for this group to achieve significant performance is very high.[50]

The modernity and diversity of the industries served also affect the character of technical service. In the information industry, most companies are newly established and handled by people with professional education and training. Most components used are internationally standardized. And many companies with foreign investment also provide good models especially in industrial engineering for local companies. So, relatively speaking, there are not many "trivial" service projects for ERSO to work on. ERSO thus concentrates on larger system service projects, such as computerization for gas stations and train and bus ticketing.[51]

By contrast, automation service is in great demand in nearly all industries, especially "old ones." The needs are diverse, many jobs are fragmented, and the industrial people with whom the service group should cooperate mostly lack education and training in modern information and automation technology which has progressed so fast in recent years.[52] So the automation service group has to operate in a very different way.

3.8. Mutual Support between Technical Service and R&D

The importance of "mutual support" between technical service and R&D is demonstrated in the automation program. Before the start of the national program, two important organizations had already existed for years. One is the Metal Industry Development

Center (MIDC), established in the mid-1950s under the financial and technical assistance from the United Nations to help modernize the machinery industry. The other is the Metal Industry Research Labs (MIRL)--renamed Mechanical Industry Research Labs (also MIRL) in 1982, established in the late 1960s to develop more advanced mechanical engineering technology.

Initially, MIDC's leader was also the founding director of MIRL. Under MIRL, a big metallic materials research department located at exactly the same place with MIDC in south Taiwan closely supported MIDC's technical service to the industry. The geographical proximity and common leadership apparently are the major cause for this cooperation.

However, when the mood of "new automation technology" prevailed in the late 1970s, many people challenged MIRL's old strategy focusing on "traditional" products, such as milling machines. MIRL's original purpose was to acquire the whole system machine tool technology and to cultivate expertise for further development.[53] But its technology transfer to local industry was not satisfactory despite its success in developing a number of high-value "whole machines."[54] Finally, a new director of MIRL, the chief designer of the automation program, reoriented MIRL to speed up R&D on CNC machine tools, robots, FMS, automatic warehousing, CAD/CAM/CAT, etc., and established a new Automation Technology Development Center in MIRL alongside the existing Precision Machine Tool Center in the central Taiwan. In the meantime, the metallic materials research unit in south Taiwan was detached from MIRL and merged into the newly formed Materials Research Labs.

From then on, MIDC and MIRL were under different leadership. The traditional intense personnel and information exchange was retarded. MIDC's technology became obsolescent quickly, though it had already had "aging problems." And MIRL, though having its own team to do service to industry, still faced many difficulties in technology transfer.

In order to strengthen the automation technical service, a new independent team--the Factory Automation Task Force (FATF)--was organized in January 1983 under the Economic Minister and planned

to operate for only two years. Under the strong leadership of a very experienced industrial technologist, FATF's diligence and service gained nationwide reputation. So it was expanded to include more than one hundred specialists and could not be dismissed at the end of the second year. In the meantime, FATF found that most local factories also needed assistance in quality control, production management and so forth.

As far as government-sponsored management consultation to industry is concerned, the China Productivity Center (CPC) has been the major responsible organization since its inception in the mid-1950s when the post-war "productivity movement" boomed. It, like many other countries' national productivity centers, played an important role in introducing many "scientific management" methods, such as statistical quality control, from the U.S. But its long history resulted in a conservative and stagnant culture. Nevertheless, its expertise could potentially complement FATF, and FATF might also bring new vigor to CPC. So the government decided to merge the two organizations. In November 1984 FATF's leader took over CPC's presidency; from June 1985 FATF and CPC staff worked at the same location; and the title of FATF was cancelled in January 1986.

However, another serious issue in automation service came to the fore. It is due to the fact that most local companies in desperate need of help are not technologically advanced ones. So despite their broadened industrial experience, many service engineers' technical capabilities "plateau" after some years' field work, and many feel "fatigue" and "burned out." Some measures--including short-term local and foreign training--do not suffice.[55] For many of them, rotation to some high-tech R&D labs to work with competent peers for some time may be desirable. But CPC/FATF does not have a strong R&D department because its principal mission is in technical service.

Nowadays the major forces in the automation program--MIDC, MIRL and CPC/FATF--are all quite "independent" in their operation. There is no evidence of intense exchange and cooperation among

them. And the "structural problems" they have faced as mentioned above still exist.

4. Impacts on S&T Development Systems and Infrastructure

4.1. Administrative Challenges by National Programs

After the initial stage of these national programs, mainly supervised by K.T. Li, several ministries took over the major responsibilities. Most administrative agencies, however, were not very capable of assessing R&D proposals, monitoring implementation, and evaluating performance. Moreover, many supervisory departments were further "trapped' in another embarrassing dilemma. Many leaders of R&D institutions were also key members on the directing or advisory committees, and some were even close advisors to high-level government officials. Accordingly, many R&D projects were teased by administrative departments as nearly self-approved and self-evaluated.[56] To cope with this situation, many administrative agencies began recruiting and consulting technical experts. This action accelerated the formation of a new group of professional technocrats and outside advisors who usually clustered in each ministry's science and technology advisory office. In some cases, this new group has more influence and power than the formal office of chief technical supervisor, the highest technical position in each ministry, due to its flexibility in practice without close ministerial or congressional scrutiny.[57]

In management, the industrial technology programs experienced the most reshuffle, whereas the basic research and medical projects the least upheaval.[58] The main reason lies in the different organizational principles and challenges.

In the basic research community, represented by the National Academy of Sciences and universities, the organization is mostly discipline-oriented, small in workteam size, and distant from the pressure of the application world. In medical projects, the prevention plan is handled in a normal way as in other disease and epidemic prevention plans by a large number of existing professional administrators,[59] and the research is assigned mainly to medical

research institutes, also medical discipline-oriented. By contrast, the industrial technology group is less discipline-oriented, more mission-oriented, evaluated eventually by economic and commercial criteria, and in many cases organized in much larger, closely integrated working teams for specific products, processes and even industries. Therefore, the management in this group faces far more challenges and difficulties than the above two groups.

4.2. Managerial Challenges to Major R&D Organizations

Since major applied R&D institutes have to play a central role in advising, planning, coordinating, and executing these national programs, they usually have to upgrade themselves to be more qualified for these missions. Taking the largest industrial R&D institute as an example, a comprehensive plan of as long as ten years' horizon was first taken into consideration in the early 1980s. In its preliminary work, an overall scheme to strengthen its management was required.[60] This scheme identified nineteen crucial managerial issues currently faced by the institute, and suggested various combinations of six major means as below for individual issues.

- upgrading of policy making and strategy formulation
- upgrading of planning under existing policies and strategies
- improvement of human relations and behavior
- improvement of organizational functions and structure
- education and training of concerned staff
- recruitment of new staff

Of the nineteen issues, the following were judged to be of high priority:

- redefinition of socio-economic missions
- project selection and resource allocation
- assessment of performance
- improvement of creativity and productivity
- contractual cooperation with government and industries
- technology transfer and diffusion
- technical consultation and service
- development of technology management

Exhibit 4 summarizes this managerial improvement plan. It is noteworthy that, by upgrading policy and strategy formulation and education and training, most of the urgent problems could be largely alleviated.

Although no other R&D institutes were known to have initiated "explicit" management improvement plans as this large one, many of them are expected to have also been strongly impacted by national programs in a similar way.

4.3. Cross-Fertilization with Grand Development Plan

In this new technology movement, *ROC's National Science and Technology Development Plan*, first announced in 1980, aimed at upgrading the general infrastructure and capabilities. More specifically, its essential points could be re-categorized into eight groups of strategic dimensions as follows:[61]

- overall planning and coordination
- human resources
- financial resources
- research and development
- technology transfer
- information
- public understanding and support
- international cooperation

Since all the main strategic measures are required in implementing the programs, the overall development framework is thus supporting the eight national programs. Meanwhile, in these programs many strategic and tactical means have to be considered systematically and synergistically. These programs "reciprocally" help integrate and mobilize the otherwise loosely interlinked or implemented grand plan. Exhibit 5 outlines the key decisions and investments in the grand plan supporting alternative energy development and energy conservation--the two major parts in the energy program.[62] In other words, these eight national programs add considerable impetus and vitality to the overall S&T development framework.

5. Managerial Implications

In major industrialized countries, the general assumption that increased R&D expenditure could do good and "spin-off" effects from military and "big science" and "big technology" programs would be significant supported the "supply-side" S&T policy during early post-war era. However, in the 1960s the "demand-side" thinking began to prevail due to the growing concern with cost-effectiveness and the better understanding of the whole process of innovation and technical change. In the meantime, many methods, such as technology assessment and R&D project evaluation, became better developed. In the 1970s the oil crisis led to more emphasis on the integration of S&T with economic and industrial policies.[63] Recently, there has been a new "movement" of focusing on "strategic technologies" through national programs of various forms in many countries. This new trend is in reality a response from many countries to the new "Japanese challenge" which is different from the old "American challenge" in the 1950s and 1960s. The "American challenge" to many countries means that "big is beautiful."[64] So the scale in firm size and in R&D investment is regarded to be crucial. "National champion" strategy and "big S&T" programs thus got popularity in many western countries. By contrast, "Japanese challenge" is characterized by a new type of national innovation system,[65] and this innovation system is well represented by the VLSI national program. Therefore, many national and international technology programs emerged outside Japan in the 1980s, also endorsing industrial collaborative R&D.

For Taiwan as a developing country, it has no similar historical locus. Until recently it had no "big science" nor "big technology," and its policy was an outright "supply-side" one. The early "American challenge" meant little to Taiwan because Taiwan was then "too underdeveloped to be challenged." However, the recent "Japanese challenge" did triggered an aspiration in Taiwan because Japan successfully caught up with and even surpassed many western forerunners from behind. To Taiwan, national technology programs aiming at industrial competitiveness thus represented an appealing

way to remedy its weakness in technology. But due to industry's overall weak technical capability, government had to take major responsibility and could not just support industrial R&D at arm's length. Therefore, national programs in Taiwan have a different picture and provide different implications from those in the industrialized countries.

In resource allocation, Taiwan's national programs in 1984 accounted for 45% of national R&D budget and 39% of national R&D personnel,[66] exhibiting the very heavy weight of these programs in the national S&T activities. In policy arena, these national programs reoriented the strategic thinking from a mere "supply-side" rationale to a "whole innovation process" approach. This approach directs the investment and restructures R&D systems.

For launching national programs, Taiwan's experience suggests that three conditions at the national level seem crucial:

- a "national champion"
- an institutional adjustment to facilitate nationwide coordination
- an overall framework to upgrade infrastructure and general capabilities

The first requisite is similar to the findings of the importance of the sponsor or "executive champion" at the corporate level.[67] This national champion should be able to acquire substantial resources, and interface and integrate various functions. The second is to provide appropriate management system and structural context. The third is to cross-fertilize national programs and is more or less like the rationale underlying the management of matrix organizations at the micro level.

In order to strengthen the still inexperienced decision-making, the organization of a foreign advisory group at the national level is desirable. These foreign advisors can contribute at the program and individual institute levels.

Because local industry lacks R&D capabilities, public applied R&D organizations have to play a pivotal role in national programs. Only as the industry gradually increases its own technical competence could the R&D institutes adopt a more indirect role and

emphasize "more generic" R&D, which in effect means a more "offensive" national innovative strategy.

Nevertheless, without strong upstream research community, downstream industry and complementary technologies, the applied R&D organizations are just like isolated "enclaves." In other words, the "whole innovation process" approach at the national level would expose the limitations and weak links in the national innovation system.

In selecting R&D topics, an "imitative" country like Taiwan could benefit greatly through national programs from technological convergence and standardization in advanced countries because of the clear foci for concerted efforts. In serving industry, when R&D has to meet diverse needs and adapt delicately to application contexts, decision making would be much more complex. Moreover, "product function-pursued" R&D would be more risky, though not necessarily more difficult, than "process-centered" R&D.

Due to the central role played by public R&D institutes, technology transfer from them to industry constitutes a big challenge. When the technology being transferred is highly complex and dynamic, the long-term, close cooperation between donor and receiver is of utmost importance because of the former's necessary deep commitment, sometimes including permanent personnel transfer, and the latter's demand for continuous infusion of new generation technology from the former if it could not reduce its dependency. In this regard, the formal organizational boundaries between both sides impose a constant uncertain, albeit not always detrimental, factor.

When the process technology is huge in investment scale, but the product design needs to be kept entrepreneurially active, Taiwan's experience shows that there is possibility for a special pattern of "strategic alliances" to come into being. That is, the government invests in the process technology and the private sector, including foreign firms, takes care of the product design. Certainly this "national strategy" requires the "openness" of the public R&D institutes to cooperate with and even to nurture a multitude of private counterparts.

In technical service to industry, usually an applied R&D organizations could not perform satisfactorily owing to a combination of lack of interest and lack of industrial "field experience." Therefore the establishment of independent technical service task forces led by experienced industrial technologists is advisable. Moreover, the potential benefit resulting from the cooperation between R&D, technical service and managerial service functions could not be overlooked, because they may be mutually supportive in the following way.

- The technical service units could provide industrial "field information" for R&D labs, and help the latter diffuse technology to industry.
- The R&D labs could "refresh" and "recharge" technical service units.
- The managerial service could complement technical service in related management improvement.

To enhance cooperation, these functions could be placed within the same organizational boundaries, under the same leadership, or at the same locations.

Because national programs are endorsed by government, mainly executed by R&D institutes, and generally fostered by grand development plans, a great request for performance would compel these "participants" to improve themselves. In Taiwan, evidence points to the possible impacts brought about by these national programs, which include the upgrading of S&T advisory and project evaluation functions in the administrative systems, the strategic re-positioning of R&D institutes, and the cross-fertilization of general plans and specific programs. In other words, these national programs could alternately exert far-reaching influence on the national development context and infrastructure.

Notes

[1] This community until the mid-1980s included the Taiwan Institute of Economic Research and some faculty members in the Economics Department of National Taiwan University.

[2] The file is being kept in STAG.

[3] To avoid inducing "sensitive reactions" from concerned people and organizations, it was decided not to include the word "management" in the title of the series.

[4] The presentations in this series in time order (all in 1985) are as follows:

March 9 *Development of Science and Technology Policy in Taiwan

March 16 *Formation of National Energy Program
*Formation of Eight National Programs

March 23 *Patterns of High-Tech and Development Strategies

March 30 *Formation and Development of IC and Computer Projects
*Formation of Industrial Materials Program
*Formation of Factory Automation Technical Service Program

April 13 *Formation and Implementation of Nuclear Energy Program
*Commercialization of Food Science and Technology

April 20 *Formation of Hepatitis B R&D and Prevention Program

April 27 *Formation of Life Science and Biotechnology Programs
*Formation and Failure of Integrated Automobile Complex Plan
*Formation of Environment Protection Program

May 4 *Cooperation between Industry and Public R&D Community
*Characteristics of Military S&T Development
*Conceptual Framework for National Development

May 11 *Incubation and Birth of Encyclopedia
*Formation and Management of University-based Industrial R&D Centers
*Establishment of Precision Instrumentation Development Center

May 18 *Challenges to R&D Professionals
*Formation of National Defense R&D Programs

May 25 *Formation of National Science Museum Program
*Issues in Urban Development and Management
*Issues in Garbage Treatment Program

June 8 *Government Administration and S&T Development
*Planning of National Health and Medical Service Network

June 15 *Development of Food Technology and Related Industry
*Strategy and Planning of National Park
*Human Factors in S&T Programs

June 29 *Planning of Regional and Land Development

*Conclusion--Formation and Management of Big S&T Programs

5 According to Chiang (1980), pp. 168-179, the sources of two most important technologies of firms in chemical industry (Chem), mechanical engineering industry (Mech) and electronic industry (Elect) were as follows:

Sources	Chem	Mech	Elect
Customers	43.4%	65.3%	65.5%
Suppliers of materials and parts	64.2%	65.3%	85.5%
Suppliers of equipments	54.7%	70.3%	54.5%
Other firms in same industry	27.4%	34.7%	23.6%
Industrial association	13.2%	8.5%	14.5%
Firms in other industries	6.7%	6.8%	10.9%
Universities	2.8%	2.5%	5.5%
Public R&D institutes	4.7%	16.1%	10.9%
Engineering consulting firms	5.7%	4.2%	5.5%
Government non-R&D agencies	3.8%	10.2%	10.9%
Outside individuals	20.8%	26.3%	23.6%

6 The overall major technology sources in terms of domestic vs foreign ones are 58% vs 45% in chemical industry, 71% vs 48% in mechanical engineering industry, and 54% vs 56% in electronic industry. Because some firms relied equally on both sources, the totals are above 100%. See Chiang (1980), pp. 168-179.

7 "NIH syndrome" refers to an attitude with which people in the R&D organizations are proud of themselves so much that they could not believe something "not invented here" would be better than theirs.

8 According to the Energy Committee of the Ministry of Economic Affairs, in 1977 oil accounted for 78% of energy consumption, and 98% of oil was imported.

9 It is often joked in Taiwan that Taiwan has only stone for cement industry.

10 According to the Council for Economic Planning and Development (CEPD), raw materials accounted for 66% of import value in 1977. This figure was 62% in 1987, not much different from that of ten years before.

11 According to CEPD, the ratio of total trade to GNP in 1977 was 93.4%. This ratio ten years later in 1987 was 99.7%. According to OECD (1987) in 1983 only three countries in OECD had this ratio higher than 90%: Belgium/Luxembourg

133%, Ireland 112% and the Netherlands 107%. The fourth one Norway was 61%, well below the first three.

12 According to CEPD, the relative contribution share of capital increase (Capital), labor increase (Labor) and technology progress (Tech) to economic development (Econ) measured by average annual growth rate is as below.

Years	Econ	Capital	Labor	Tech
1953-1960	7.57%(100%)	(8.3%)	(14.7%)	(77.0%)
1961-1970	9.64%(100%)	(18.9%)	(20.9%)	(60.3%)
1971-1977	9.75%(100%)	(34.7%)	(24.7%)	(40.6%)

13 According to the Health Administration, in the early 1980s the rate of infection (measured by detection of antibody) of hepatitis B in Taiwan was 70% at the age of 20 and 90% at the age of forty. The number of antigen carriers was about three million, or 17% of the total population. Similar results were found in Southeast Asia and South China. This high percentage of carriers is in striking contrast with the average 5% of world population, 7% of whole Asians, 2% of Japanese and 0.5% of Americans.

14 Hepatitis B was found to be highly correlated with cirrhosis and hepatoma. The development of plasma vaccine was only getting initial success in the early 1980s in France and the U.S.

15 The legacy of R&D and extension establishments from Japanese colonial era until 1945 and the local movement in parallel with the post-war "Green Revolution" contributed greatly to Taiwan's agriculture.

16 See STAG (1988), p. 18.

17 For offensive, defensive, imitative, dependent, traditional and opportunist innovation strategies, see Freeman (1982), pp. 169-186.

18 See Chiang (1989), p. 247.

19 In 1980, electronic and mechanical engineering industries were announced by the government as "strategic industries" after the Second National Economic Meeting. The output value of information industry in 1988 was USD 52 billion, accounting for one third of that of the electronic industry and ranked as world's sixth largest. Relevant information is from the Institute for Information Industry.

20 The statistics should be taken with caution due to the inexperience of census of R&D activities in Taiwan. Moreover, statistics in the 1970s was

gained through providers' estimate of previous years' expenditure in the early 1980s. The information is from STAG.

21 This criticism was very strong around 1980 and finally led to the change of highest management in CIRL.

22 This evaluation was made in the 9th General Science and Technology Advisory Board Meeting in March 1987.

23 See *Fortune*, June 22, 1987, p. 114.

24 The 1982 conference on genetic engineering was the first attempt to systematically introduce "new biotechnology" to Taiwan.

25 See U.S. OTA (1984), pp. 99-103.

26 The statistics is from Dataquest.

27 See Ranta (1988).

28 The information about South Korea is from ERSO.

29 The information about computers is from ERSO.

30 The statistics is from the Institute for Information Industry.

31 The information is from ERSO.

32 This was announced by the vice president of ITRI in the annual conference of Taiwan's Computer Society in 1989.

33 This impression was expressed by a high-ranking manager in ERSO.

34 This policy was emphasized in a speech delivered by the vice president of ITRI, who is also a former ERSO managing director, in June 8, 1989.

35 This is the author's memory of what happened in 1983 without records at hand.

36 The history of main actions could be found in a small English language booklet "Automation" published by STAG in 1988.

37 This is integrated from the information from the Energy Committee and three speeches delivered by the president, a former president and the director of nuclear engineering department of Taiwan Power Company in a conference held in Taipei in April 29, 1986.

38 This information is cited in Taiwan Power Company's 1987 Annual Nuclear Operations Report.

39 In 1984, the average availability rates of PWRs in the U.S., France, Japan, FRG, Sweden and Switzerland were 60%, 82%, 73%, 83%, 67% and 89% respectively; and those for BWRs in the same country order but without France

were 48%, 72%, 79%, 81% and 89%. See Hansen et al. (1989). Certainly this is only a rough comparison with many factors oversimplified.

[40] The information is from an ITRI's evaluation report of IC project published in 1987.

[41] The information is from ERSO and Lin (1988), pp. 32-38.

[42] The history of later IC development in Taiwan is based on several interviews with Kuo Shan Co.'s 5 key founders in California in July 1987 and information sparsely from ERSO.

[43] See Lin (1988), p. 41-42.

[44] *Central Daily News* (in Chinese), July 11, 1987, p. 7.

[45] *Commonwealth Monthly* (in Chinese), June 1987, pp. 148-154.

[46] See Lin (1987), pp. 38-40.

[47] This is the author's understanding of MRL's practices.

[48] This is a rather common opinion shared by many people, including the leading advisor to the energy national program in STAG.

[49] This is the comment from several "insiders" of the two energy companies and the president of an energy conservation consulting company.

[50] This is based on the author's observation due to his involvement in planning energy conservation demonstration.

[51] The technical service information is from ERSO.

[52] This is the author's observation while participating in the Factory Automation Task Force's first two weeks' field visits to local industry in January 1983.

[53] The information is from a former deputy director of MIRL's Precision Machine Tool Center.

[54] For example, MIRL's milling machines were successfully exported to foreign professional users at six times the price of comparable products of local makers. But few local machinery makers believed they could enter into such a high-quality and high-price market in the near future. Many argued that MIRL should focused on "key element technologies" instead of "whole machine technology." This is the author's memory about what happened in MIRL then as he worked in the old MIRL for several years.

[55] This is the author's experience as he served as the director of human resources in CPC beginning in November 1, 1984 when the merger process of CPC and FATF formally started. The author was then the only one affiliated to

neither CPC nor FATF with the responsibility to facilitate the personnel merger and to help human resources development.

56 The largest industrial R&D complex's projects were often so pictured by the responsible departments in the Ministry of Economic Affairs.

57 This is obviously the case in the Ministry of Economic Affairs with which the author had close contact.

58 For instance, only at the managing director level (the highest executive position in an R&D and technical organization), the reshuffle (excluding "real promotion" or "natural retirement") due to "unsuccessful missions" happened in chemical labs (twice, 1981 and 1985), mechanical labs (1982), energy labs (1985) and productivity center (1984). All these labs are so-called "national labs" as well as leading institutes in the national programs. In the basic research and medical research organizations, there has not been reshuffle due to similar reasons at this level during the above period.

59 As an informal tradition in Taiwan, normally the director of the Health Administration is a medical doctor, and the chief technical supervisor is a public health professional. Besides, most department and division heads also own advanced professional degrees.

60 The author was responsible for this job. See Chiang (1984).

61 Chiang (1980), pp. 252-256.

62 This exhibit was created by modifying a similar one presented by the author in the meeting in June 29, 1985 as part of the conclusion of the seminar series "the Formation of Big Science and Technology Programs" as mentioned in Note 4.

63 For a historical review of major industrialized countries' post-war S&T policies until around 1980, see Freeman (1982), pp. 189-206.

64 This is the main argument in the famous book written by Schreiber (1968).

65 See Freeman (1987) for Japan's national innovation system.

66 The statistics is from *ROC's Science and Technology Annual Report 1986* (in Chinese) published by the National Science Council.

67 See Maidique (1980) for corporate champion and technological innovation.

Exhibit 1. Division of Labor in National Biotechnology Program

	BR	AR	D	C
Promotion Organizations				
• National Academy of Sciences	├-----┤			
• National Science Council	├-----┼---			
• Council of Agriculture		├-----┼----		
• Health Administration		├-----┼----		
• Ministry of Economic Affairs			├------┼---	
• Ministry of National Defense			├------┼---	
Implementation Organizations				
• National Academy of Sciences	├-----┤			
• University Departments and Institutes	├-----┼-----┤			
• Agriculture Experimental Research Institutes			---┼------┼-	
• Development Center for Biotechnology			-┼------┼-	
• Industrial Technology Research Institute		├-----┼------┼-		
• Food Industry Research and Development Institute		├-----┼------┼-		
• Public and Private Firms		├-----┼------┼------┤		

Note:
BR: Basic Research
AR: Applied Research
D: Development
C: Commercialization

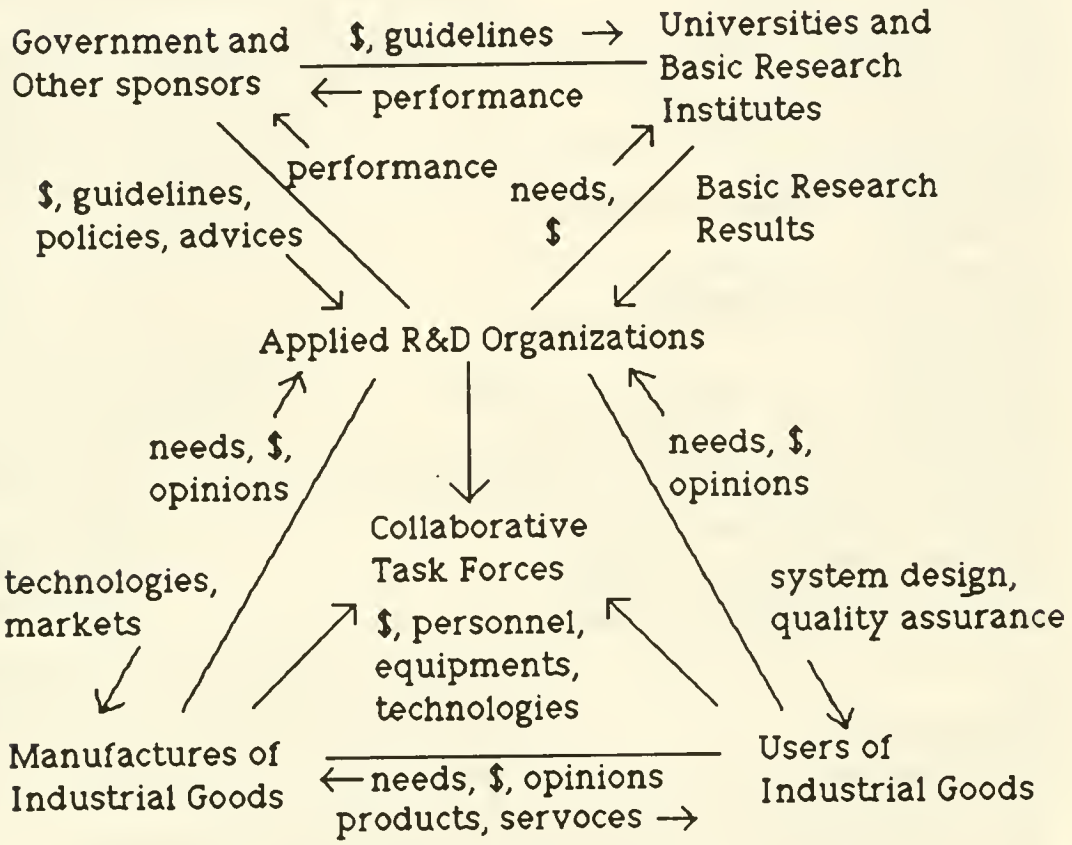
Source: Science and Technology Advisory Group.

Exhibit 2. Taiwan's Manpower in Information Industry in Mid-1980s

Product Development Stage	Key Manpower Needed	Availability
1. Product Concept Definition	Experienced Design Manager	Few
	Experienced Marketing Manager	Few
2. System Design (System Specifications)	Experienced Design Manager	Few
	System Design Engineer	Few-Some
3. Product Engineering Design (For Cost Reduction, Quality Assurance, etc.)	Experienced Design Manager	Few-Some
	Design Engineer	Some
4. System Development (According to 2 and 3)	Design Project Manager	Few-Some
	Design Engineer	Some-Many
5. Manufacturing	Field Engineer	Many

Source: Chiang (1989), p. 247.

Exhibit 3. Collaborative Framework in National Programs



Source: This research.

Exhibit 4. Managerial Improvement Plan in A Large R&D Complex

Crucial Managerial Issues	Major Means						Priority
	A	B	C	D	E	F	(O:high)
• Socio-economic Missions	*				*	X	O
• Objectives of Organizations			X		*	X	
• Project Selection & Resource Allocation	*				X	X	O
• Project Management	*	X	X	*	*		
• Assessment of Performance	*	X			*	X	O
• Organization of Institutes and Labs			X				
• Organization of Teams			X				
• Recruitment, Training and Evaluation of Personnel	*	X					
• Improvement of Creativity		X	*	*			O
• Improvement of Productivity		X	*	*	*	*	O
• Cooperation between R&D and Non-R&D Departments			*	X			
• Communication and Coordination of R&D			*	X			
• Management of Cost and Expenditures					X	*	
• Contractual Cooperation with Government	*					X	O
• Contractual Cooperation with Enterprises	*					X	O
• Technology Transfer and Diffusion	*					X	O
• Technical Consultation and Service		*				X	O
• Forecast of Technology and Needs	*	X					
• Development of Technology Management	*	X					O

Notes:

1. Major Means
   - A: recruitment of new staff to take responsibility
   - B: education and training of concerned staff
   - C: improvement of organizational structure and functions
   - D: improvement of human relations and behavior
   - E: improvement of planning under existing policies and strategies
   - F: improvement of policy making and strategy formulation
2. Importance of Major Means
   - X: very important
   - *: important

Source: Chiang (1984), pp. 24-25.

Exhibit 5. Measures in National S&T Plan Needed to Support Alternative Energy Development and Energy Conservation Projects

Main Decisions & Investments	Alt. Ener. Proj.	Ener. Cons. Proj.
1. Overall Planning and Coordination		
•Government Leading Departments		
-Premier Office		X
-National Science Council	*	
-Economic Ministry	X	X
-Defense Ministry, etc.		
-Local Governments		
•Major Participants		
-Government	X	X
-Academic Community	*	
-Applied R&D Institutes	X	*
-Industrial Corporations		X
-Consulting and Service Agencies		X
-Industrial and Trade Associations		*
•Regional Programs		
-Urban Areas		X
-Rural Areas		*
•Environment and Infrastructure		
-Technology-push Strategy and Measures	*	
-Demand-pull Strategy and Measures		X
2. Human Resources		
•Science and Technology Expertise		
-Scientists	*	
-Engineers	X	X
-Technicians	*	X
-Skilled Workers	*	X
•Promotion and Application Expertise		
-Marketing Specialists		X
-Technology Transfer Specialists		X
-Supporting Staff		
•Managerial Expertise		
-R&D and Technical Organization Leaders	*	X
-Project Leaders	X	X
-Managerial Staff		*
•Team Formation		
-Availability of Constituents	*	X
-Appropriateness of Integration Mechanism	*	X

Main Decisions & Investments	Alt. Ener. Proj.	Ener. Cons. Proj.
3. Financial Resources		
•Ultimate Responsibility Sources		
-Beneficiaries		X
-Causers		X
-General	X	*
•Investment		
-Government Budget	X	*
-Private Sector Budget		X
•Allotment		
-By Areas and Organizations		
-By Scales		
-By Urgency		
•Utilization Efficiency		
-Improvement of Financial System		X
-Upgrading of Financial Personnel	*	X
4. Research and Development		
•Horizontal Integration		
-Key Ingredient Disciplines	X	*
-Multidisciplinary Coverage and Cooperation	X	X
-Including Social Sciences and Humanities	*	X
•Vertical Integration		
-Basic Research	*	
-Applied Research	X	*
-Development and Engineering	*	X
-Commercialization	*	X
-Promotion of Applications		X
•Project Management		
-Uni-organizational Management	X	*
-Multi-organizational Management	*	X
5. Technology Transfer		
•Introduction from Foreign Countries		
-Public Sector	*	*
-Private Sector		X
•Domestic Technology Transfer and Diffusion		
-R&D Institutes	X	*
-Manufacturers		X
-Consulting and Service Agencies		X
-Industrial and Trade Associations		*

Main Decisions & Investments	Alt. Ener. Proj.	Ener. Cons. Proj.
-Subcontracting Systems		
•Abandonment of Obsolete Technology		
-Scheduled		X
-Export Feasibility		
6. Information		
•Network		
-General Purpose Data Bases		X
-Special Data Bases	X	X
-Service Channels		X
•Utilization		
-Restricted	*	
-Unrestricted		X
7. Public Understanding and Support		
•Fundamental Education		
-Formal Education Curriculum	*	X
-Supplementary Programs	*	X
•Mass Media Emphases		
-Television	*	X
-Newspapers	*	X
-Magazines	*	*
-Exhibitions		*
•Support to Publication/Production Industry		
-Relevant Information Supply		X
-Joint Campaign		*
-Financial Support		
-Managerial Support		
•Communication with Opinion Leaders		
-Nationwide		X
-Regional and Local		*
8. International Cooperation		
•Information Exchange		
-Science and Technology Information	X	X
-Industrial and Other Relevant Information		X
-Translation		X
•Human Exchange		
-Individual Experts	*	
-Groups and Teams	*	*

Main Decisions & Investments	Alt. Ener. Proj.	Ener. Cons. Proj.
-Organizational Arrangement and Supporting	X	X
•Joint Programs		
-Consideration of Potential Cost and Benefit		X
-Emphasis on Collaborative Mechanisms	*	*

Note: Degree of Importance: X Very important * Important
Source: This research.

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